RESULTS OF A WINGDES2/AERO2S FLAP OPTIMIZATION FOR THE TCA

57/02

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Bibliography

- *Design of Supersonic Transport Flap Systems for Thrust Recovery at Subsonic Speeds;* Mann, Michael J., Carlson, Harry W., and Domack, Christopher S.; NASA/TP-1999-209536, December 1999.
- *Survey and Analysis of Research on Supersonic Drag-Due-to-Lift Minimization with Recommendations for Wing Design;* Carlson, Harry W. and Mann, Michael J.; NASA TP 3202, September 1992.
- *Validation of a Computer Code for Analysis of Subsonic Aerodynamic Performance of Wings with Flaps in Combination with a Canard or Horizontal Tail and an Application to Optimization;* Carlson, Harry W., Darden, Christine M., and Mann, Michael J.; NASA TP 2961, January 1990.
- *Validation of a Pair of Computer Codes for Estimation and Optimization of Subsonic Aerodynamic Performance of Simple Hinged-Flap Systems for Thin Swept Wings;* Carlson, Harry W. and Darden, Christine M.; NASA TP 2828, 1988.
- *Applicability of Linearized-Theory Attached-Flow Methods to Design and Analysis of Flap Systems at Low Speeds for Thin Swept Wings with Sharp Leading Edges;* Carlson, Harry W. and Darden, Christine M.; NASA TP 2653, 1987.

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There are many documents that describe the theory and usage of the linearized-flow approach over the years. The author feels that the documents listed above are chronologically significant in the history of the development of the codes, including many successful optimizations. The first document was found to be especially interesting, since the configurations described therein were similar to the TCA configuration. The method used herein is essentially identical to the method used in that report. Many of the authors are still available for consultation, and thus technical help was easy to obtain.

Analytical Background of Computer Codes

- Two codes, WINGDES2 and AERO2S, based on linear, attached-flow theory
- Nearly-attached flow ⟶ high aerodynamic efficiency
- Estimate of attainable leading-edge thrust and representation of vortex forces
- Actual performance comparable to that of a flat wing with full leading-edge thrust

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The assumption is made that a high level of aerodynamic efficiency results from a flow that is nearly as attached as possible, minimizing the real-world effects of flow separation.

The method includes an estimate of attainable leading-edge thrust and an approximate representation of vortex forces.

The combination of attainable leading-edge thrust and dustributed thrust produces performance comparable to that of a flat wing with full leading-edge thrust.

WINGDES2

- Mildest camber surface that will produce optimum performance
- A “design moment coefficient” is determined from an initial “whole-wing design”
- Subsequent runs are carried out with flap areas specified
- Result is set of flap deflections that approximate the optimum camber design
- Does not make a performance analysis based on the wing with deflected flaps

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The code defines the mildest camber surface at specified values of lift and pitching moment.
The “whole-wing design”, with no pitching moment constraint, is used initially in order to improve trailing-edge flap specifications.

AERO2S

- Used to estmate the aerodynamic performance of the wing with deflected flaps
- Results are modified to include attainable leading-edge thrust and the forces due to vortices
- Measure of performance is the Suction Parameter, which compares the drag of the configuration with upper and lower bounds

$$S_s = \frac{C_L \tan(C_L/C_{L_\alpha}) - \Delta C_D}{C_L \tan(C_L/C_{L_\alpha}) - C_L^2/(\pi AR)}$$

- AERO2S runs are made at a matrix of multiples of leading-edge and trailing-edge flap deflections
- Optimum flap defections chosen from the maximum Suction Parameter point on a contour plot whose axes are the multiples of the nominal flap deflections

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The forces due to vortices are produced by leading-edge flow separation.
The upper bound of the Suction Parameter is the drag of a flat wing with no leading-edge thrust and no vortex force.
The lower bound is the drag of a wing with an elliptical spanwise load distribution and full leading-edge thrust.

INPUT DATA

- Data for both codes were obtained from LaRC data files that were extracted from Boeing data generated during lofting

sfy 24may96 020 TCA-6 Flopt 01 Cldes=0.5, Cmdes=-0.0141

$INPT1

NPLOT=1, PFILE='wdes_020.xyp', ELAR=1.,

XM=.35, JBYMAX=18, CLDES=0.50, CMDES=-0.0141, IPRSLD=0, IVOROP=1,

RN=210., IEMPCR = 0, CBAR= 94.952, XMC=190.38, NGCS=0, IFLPDES = 1,

NLEY=20, NTEY=20, XMAX= 247.4100, SREF= 8500.0000, NYC=20,

NPCTC=20, NYR=20,

TBLEY= 0.0000, 1.6400, 3.2810, 5.6660, 5.6670, 7.3750, 9.8330,

15.4840, 17.0920, 19.6890, 22.9710, 26.2520, 29.5340, 30.8580, 35.7900,

...

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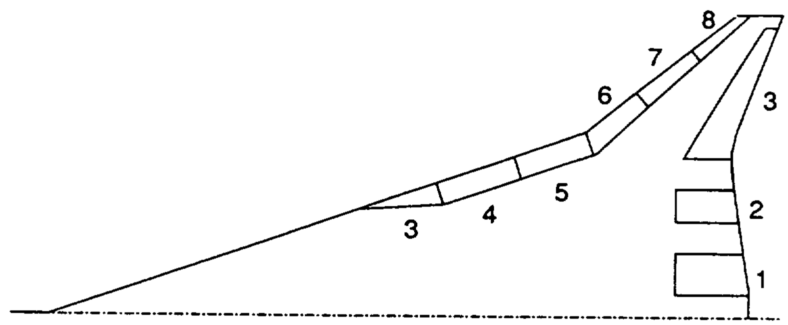
Thanks to Lori Ozoroski, NASA Langley Research Center, for providing the data files for both the WINGDES2 and AERO2S codes. The automatic production of the data files during lofting computations saved a great deal of tedious data extraction and specification.

TCA Wing Planform with Part-Span Flaps



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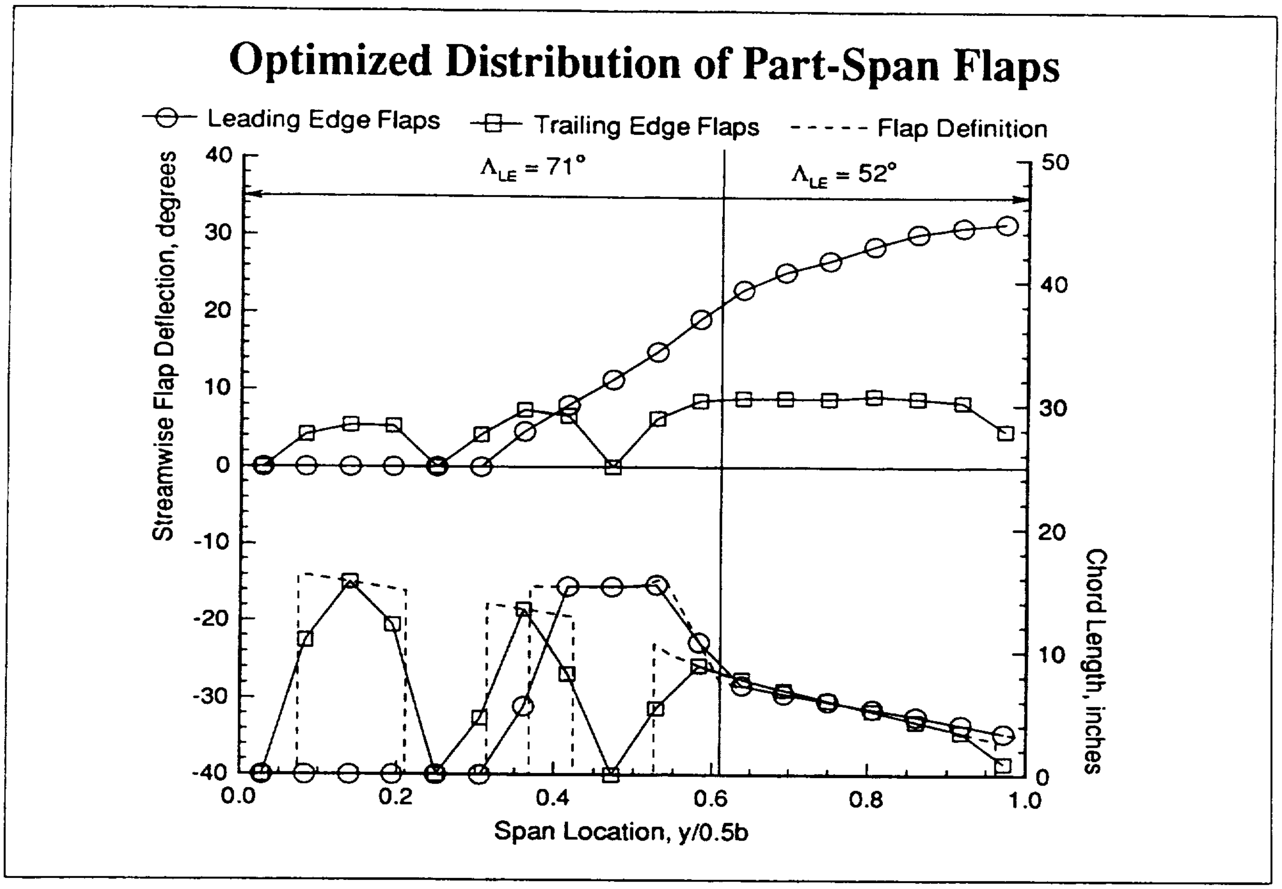
The numbering system of the flaps has occasionally varied. The system shown above will be used in this paper, along with an extended version of it for the full-span flaps. Identical flap numbers will be differentiated by specifying “leading-edge” or “trailing-edge”.



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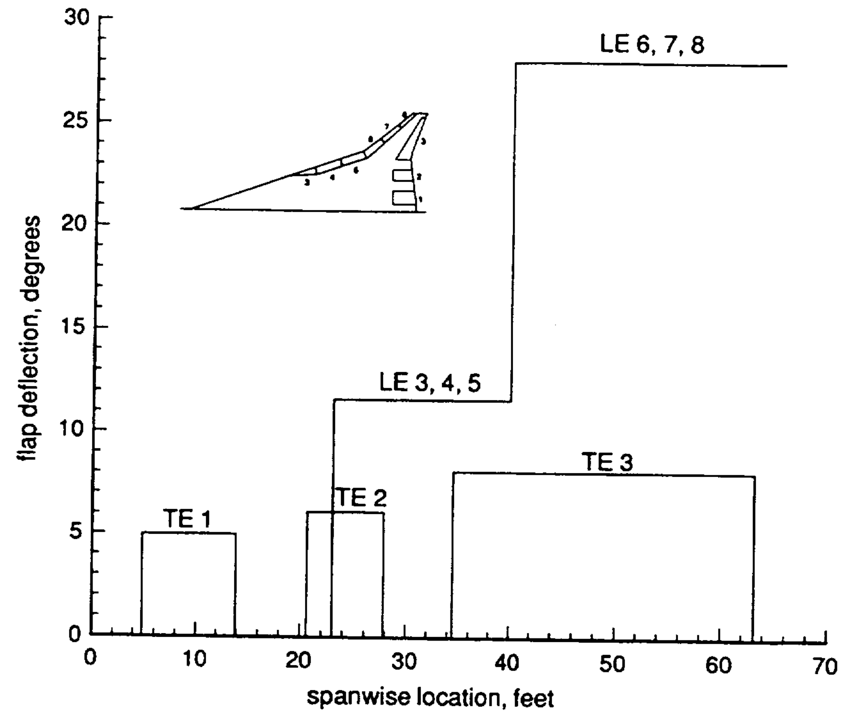
The upper curves correspond to the left-hand-side axis, and the lower curves to the right-hand-side axis.
Since the span of the wing is divided into a finite number of strips for the flap analysis, strips that include non-flap areas show their chord lengths reduced accordingly.
The flaps angles are measured in the streamwise direction.

Flap Deflection Schedule Used in AERO2S



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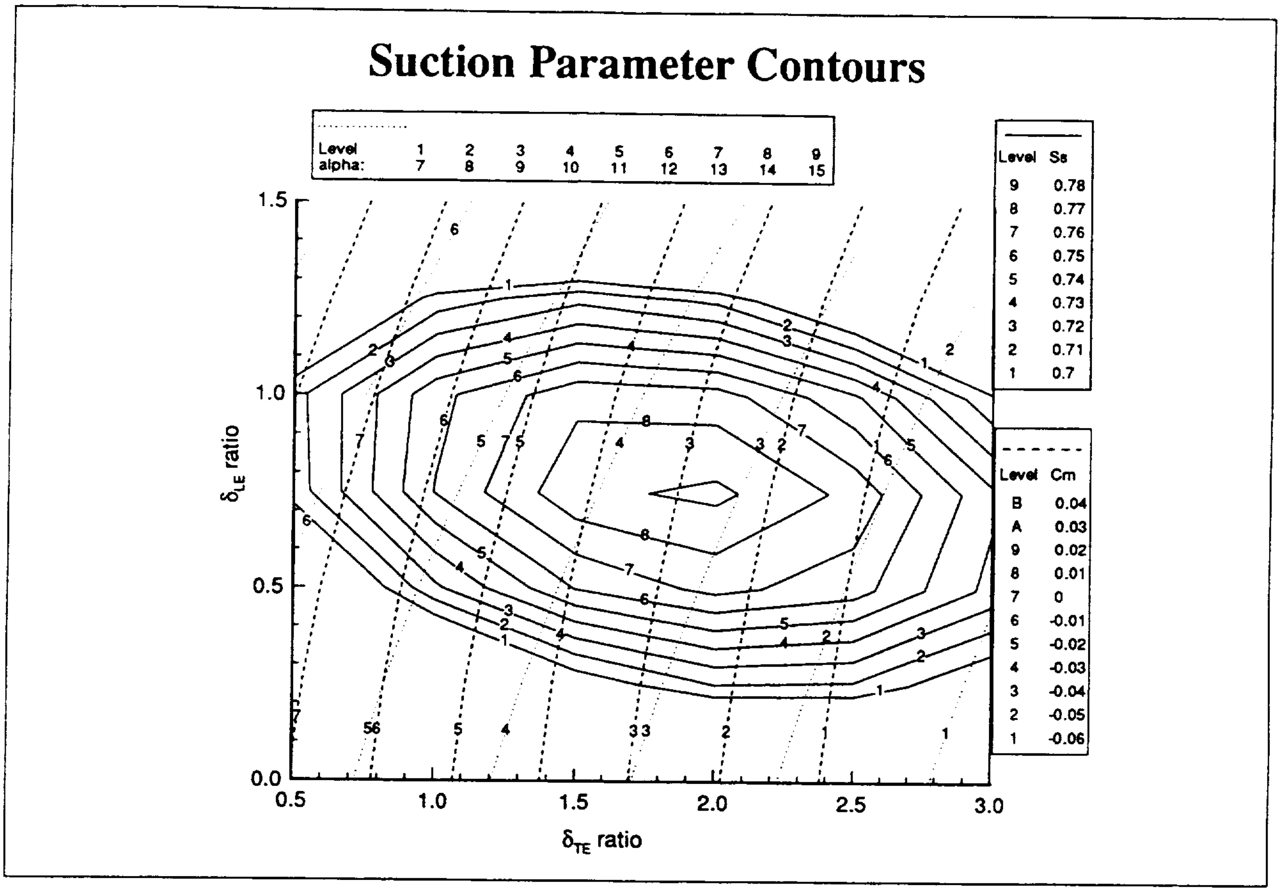
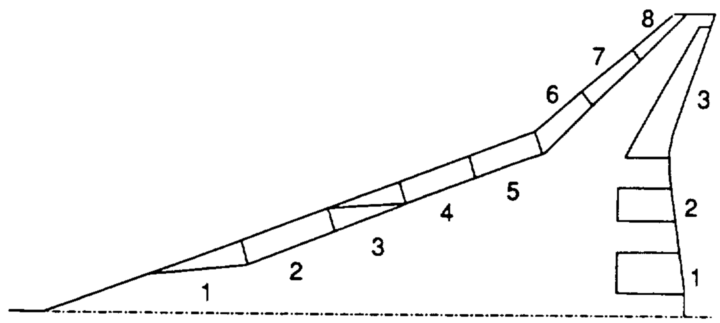
The average value of flap deflection was calculated and specified as the nominal value for that flap. Flap deflections are still specified in the streamwise direction.



The nominal values of the flap deflections are multiplied as TE and LE groups by weighting factors ranging from 0 to 3 (for this configuration) to obtain deflection ratios δ_{TE} and δ_{LE}. The resulting Suction Parameters are plotted against these ratios. An optimum Suction Parameter is apparent near $\delta_{TE} = 2$ and $\delta_{LE} = 0.75$. Also plotted are angle of attack and pitching moment coefficient.
The large number of individual calculations were carried out in a day or two, as AERO2S ran very quickly on our mainframes.

TCA Wing Planform with Full-Span Flaps



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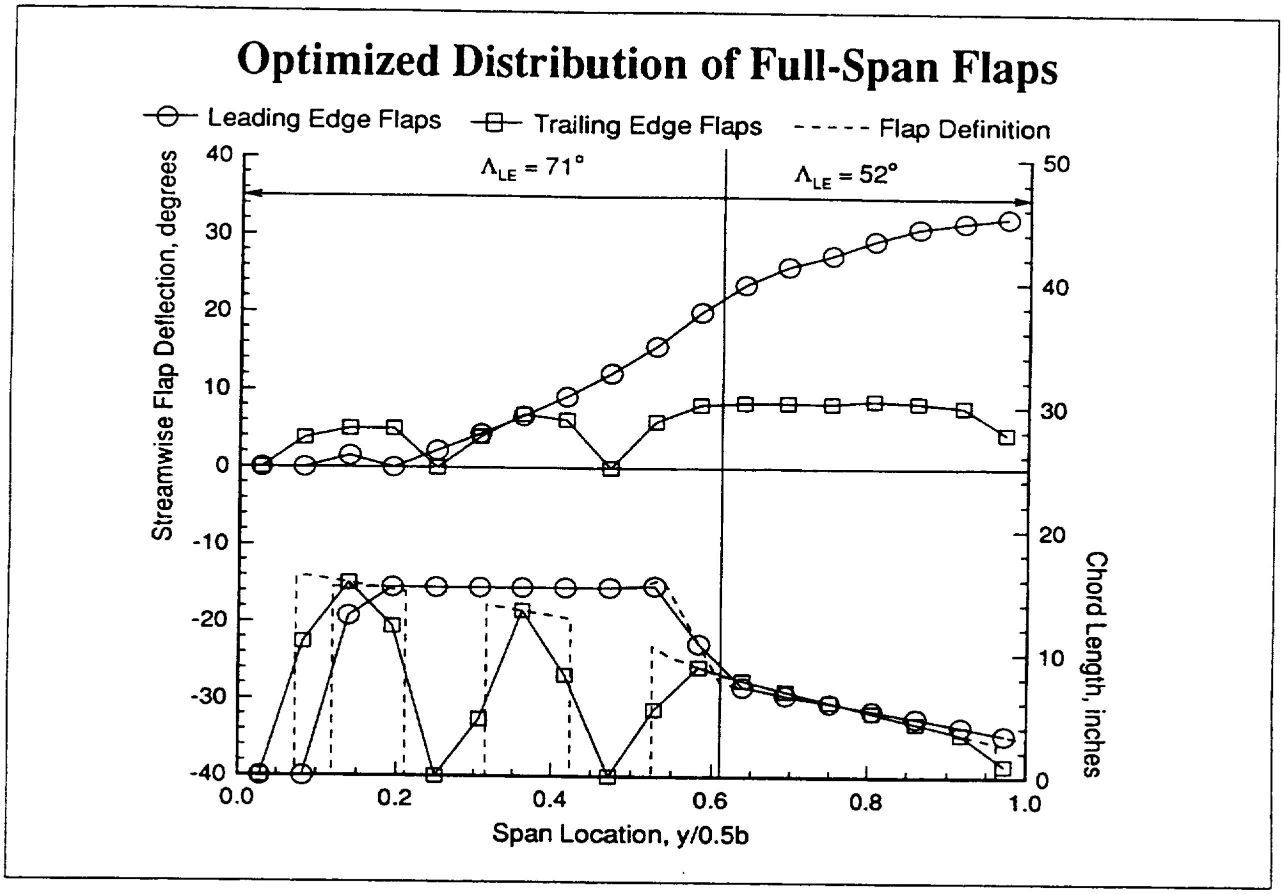
A second configuration was analyzed, the full-flap configuration, in which LE flap 3 is made a full flap, and LE flaps 1 and 2 are added. All of the leading-edge flap deflections were then re-optimized, as were the trailing-edge flap deflections. The trailing-edge flap configuration remained the same in extent.



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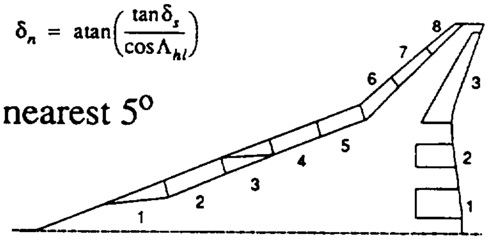
The resulting optimized distribution is very similar to the part-span flaps. Likewise, the ratioing of the deflections and optimization of the Suction Parameter resulted in similar numbers.

Application of Results to TCA

- Average deflection for each flap was calculated
- Streamwise deflection values changed to values normal to the hinge line of the flap using $\delta_n = \operatorname{atan}\left(\frac{\tan\delta_s}{\cos\Lambda_{hl}}\right)$
- Flap values rounded to the nearest 5°



Final Flap Deflection Values (degrees)

	LE Flaps								TE Flaps		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**1**	**2**	**3**
Part	0	0	45	25	25	30	30	30	10	10	20
Full	5	10	20	35	35	30	30	30	10	10	20

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The final flap deflection schedule, after reference to the local hinge lines of the flaps, indicates a great deal of similarity between the part-span and the full-span distributions. The Suction Parameters obtained were also very similar in value. Values compare very reasonably with previous flap deflection schedules derived by other means.

Conclusions and Comments

- The codes WINGDES2 and AERO2S were easy to obtain, and technical help was readily available
- The codes have a long, well-documented history of successful optimizations of various aircraft configurations
- The codes were easy to use, although specification of input data was time-consuming
- Run times were short, allowing the many runs necessary for the Suction Parameter matrix to be accomplished within a day or two
- Results of the optimization appear to be reasonable

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